

**ASSESSING THE RISK TO SUBURBAN ACTIVITIES ASSOCIATED WITH
TRANSPORT ENERGY AVAILABILITY AS A FUNCTION OF URBAN FORM**

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ABSTRACT

A method to model the energy reliance of transport activities within a suburb is described. The method employs risk analysis techniques to determine the vulnerability of suburban developments to a fuel shortage event or crisis. The focus of this work is on preliminary assessments of the vulnerability of developments, not on determining post-crisis behaviour changes, which may affect mode choices and travel patterns. Energy shortages are modelled as a constraint on existing levels of fuel consumption and vulnerability is determined by comparing current residential fuel consumption to a constrained energy availability scenario (fuel shortage). A case study in a new suburban development in Christchurch, New Zealand, illustrates the vulnerability for accessing an important activity, food shopping, and indicates the degree of impact which would precipitate behavioural and physical changes.

INTRODUCTION

Over the last fifty years, low-density suburban growth and associated commercial developments, termed sprawl, have been the dominant pattern in the developed world. There has been growing interest in understanding the dynamics of urban sprawl and the implications for long-term functional reliability of transportation systems. Sprawl development continues at a high rate due to economic drivers. Our research aims to investigate the vulnerability of suburban developments to a fuel shortage event or crisis, which is likely to affect the performance of transportation systems and community well-being. The outcomes of the research may be of use in managing urban development by including energy risk factors and fossil fuel reliance into the decision-making process.

Most research efforts have focused on studying activity-transportation system interactions and energy consumption associated with new urban developments. Some scholars have indicated that certain combinations of spatial patterns of land-use and population density can lead to less transport energy per capita for cities (1). On the other hand, it is thought that decreasing energy costs will further increase the distance of spatial interaction leading to more dispersed settlement systems creating more trips over longer distances. This has been appointed as an unsustainable trend in transport (2), because it requires continuous increase in energy supply, which is mainly originated from fossil fuels. Furthermore, urban sprawl accounts for much of the increase in energy required for new spatial settlements, because these spatial patterns consume more energy than the more compact traditional settlements (3).

Existing transportation systems are reliant on the consumption of fossil fuel, yet new suburbs and developments are being designed under the assumption that the availability of fuel and/or fuel prices will remain unchanged in the future. Also, state-of-the-art transport models and transport planning rarely consider energy as an integral part of the transport system (4). Models for transport energy have been developed, most commonly focusing on mode change and its relation to energy consumption and more recent literature relates energy to spatial patterns of urban settlement (5) (6). Furthermore, energy is not currently considered in risk-analysis or reliability of transport systems, disregarding any potential shortage and/or price increase scenarios, which are debatable but cannot be ignored in planning activities.

This work describes a method to analyze the vulnerability of suburban developments to fuel shortages as a function of physical urban patterns and vehicle mode reliance. The method uses risk analysis techniques to measure the ability to continue normal suburban functions in a fuel shortage event. Although acknowledged that real fuel shortages have complex effects on mode change and behaviour, the focus of this work is on preliminary assessments of the vulnerability of developments, not on determining the behaviour changes which might occur after a crisis. Therefore, energy shortages are modelled as a constraint on existing levels of fuel consumption and vulnerability is determined by computing the difference between current energy use and the constrained energy available during a fuel shortage event or crisis. The method is applied to a case study in order to assess the vulnerability associated with food shopping in a new suburban development in Christchurch, New Zealand.

After this introduction, section two presents the description of the method to assess the reliance on transport energy. The application of the method to the case study is described in section three. Finally, section four comprises the conclusions and introduces recommendations for future studies.

METHOD TO ASSESS THE RELIANCE ON TRANSPORT ENERGY

Be a suburb or a new urban development that comprises a built environment. During a transport energy shortage, the built environment will intrinsically have a resilient ability to provide accessibility to activities within suburban boundaries. Given the suburban current state of transport energy consumption for accessing a specific activity (shopping, education or work), this method analyses the range of possible changes to the built environment and residents behaviour according to energy risk scenarios.

The method has six steps. Based upon the diagnosis of study region (suburban or new development) in step one, current energy consumption is estimated in step two. Next, accessibility scenarios are defined in order to perform the risk analysis for current conditions. In step four, transport energy constraint scenarios are then simulated for the region taking also in consideration likely scenarios of suburban residents' behavioural changes (mode, frequency, in response to energy constraints. Next, changes in the built environment are simulated in order to cope with energy scenarios. Finally, step six focuses in analysing the effectiveness of behavioural and physical changes in order to assess the vulnerability of the study region. These steps are detailed in the following sub-sections.

Step One: Define The System For Analysis

The system consists of the built environment and Residents Behavior (RB) within a suburb (or study region). The built environment is defined as the number and layout of households and the activity locations and how they are connected to the transport network. RB is defined as mode choice and trip frequency of residents completing a specific activity.

Step Two: Define The Variables And Estimate The Current Energy Consumption

Energy consumption is a function of the built environment and behaviour of residents within a suburb. The total energy consumption of the study region will be a summation of the energy consumption across all households within the region. The built environment consists of two variables: trip length (TL_{ij}^m) from the household (or group of households) i to the activity location j and energy consumption (EC_{ij}^m) of the mode m used to access the destination (activity location j). RB is expressed in terms of the trip frequency (TF_{ij}^m) associated with mode choice m . So the energy consumption is represented as:

$$E_{ij}^m = f(TL_{ij}^m; EC_{ij}^m; TF_{ij}^m)_m \quad (1)$$

$$E = \sum_m \sum_j \sum_i E_{ij}^m \quad (2)$$

where

f is a weighting function that establishes the relationship between the energy consumption and the built environment and resident's behaviour variables.

TL_{ij}^m = Trip length from household to activity – Distance (e.g. kilometres);

EC_{ij}^m = Energy consumption of mode used – Volume/Distance (e.g. litres/km);

TF_{ij}^m = Frequency of trips made to activity – Number/Time (e.g. trips/week);

m = Mode used to access activity – Dimensionless (e.g. car, bike etc...);

E_{ij}^m = Energy consumption per household and activity location – Volume/Time (e.g. litres/week);

E = Energy Consumption of Defined Region – Volume/Time (e.g. litres/week)

Observed data expressing TL_{ij}^m , EC_{ij}^m , and TF_{ij}^m is converted to probability distributions using the Monte Carlo Simulation, which allows probability variables to be represented by mathematical distributions rather than a single value. Each distribution contains a complete range of possibilities for the variable of interest. The variable distributions represent the individual probabilities for the entire range of possible outcomes. These distributions can then be multiplied together to produce a resultant probability distribution that shows the complete range of possible outcomes for many variables and their probabilities (7). This involves creating probability distribution functions ρTL , ρEC and ρTF that estimate the data for individual TL_{ij}^m , EC_{ij}^m , and TF_{ij}^m values.

Separate energy consumption and trip length distributions are calculated for each mode, noting that some modes may produce zero energy consumption (e.g. walking). The energy consumption for each mode is then summed to produce the probability distribution of total energy consumption for the region for all modes (ρE) as shown in equation (3).

$$\rho E = \sum_m \rho TL^m \cdot \rho EC^m \cdot \rho TF^m \quad (3)$$

Step Three: Perform Risk Analysis And Define Behaviour Change Limits For The Study Region

The risk of loss of accessibility faced by residents is dependent upon their reliance on transport fuel. High risk is therefore defined as a high level of reliance on transport fuel. There are two main impacts that may affect residents in a transport energy shortage, these are: forced behaviour modification (reducing the frequency of trips or changing modes) and loss of access to an activity (resident is unable to modify his/her behaviour). All identified impacts are categorised in Table 1 in descending order from greatest to least impact. Distance (d) is taken as the parameter in order to compare the current distance (d_a) that residents are likely to walk to the activity location and the maximum feasible walking distance (d_{max}), which can be either empirically or arbitrary determined according to data availability.

Step Four: Simulate Energy Constraints And Determine The Resilience Of The Built Environment

Given scenarios of energy constraints, this step focuses in estimating behaviour changes observed in the region's residents. Each transport energy constraint scenario first requires the level of constraint to be pre-determined as a percentage constraint (g) of the current consumption. After estimating the constrained energy consumption by applying equation 4, Constrained Energy Supply (CES) is compared against Energy Consumption Estimation (ECE) in order to identify the need for behaviour changes (step B).

$$E_{[ct]} = g \cdot E_{[cu]} \quad (4)$$

Where:

$E_{[ct]}$ = Constrained energy consumption; and

$E_{[cu]}$ = Current energy consumption.

The behaviour variables mode share and trip frequency are first individually modified to meet the applied constraint. To determine the resilience of the built environment both behaviour variables are adjusted to their maximum limits to produce the minimum feasible energy consumption for the study region.

As fuel supply is constrained, fuel consumption is equally constrained ($E_{[mc]}$) by simulating a change from motorised modes to non-motorised modes. This results in a reduction of energy consumption for the region, allowing energy consumption to equal the simulated constrained supply (equation (4)). Changes in mode share are induced by forcing residents within a certain distance (d) of the activity location to use a non-motorised mode (zero consumption) to access the activity location. This distance (d) is increased (forcing more residents to use non-motorised modes) to match the simulated increasing constraints in fuel supply. This is represented as:

$$E_{[mc]} = E_{[ct]} = gE_{[cu]} \quad (5)$$

$$E_{[mc]} = \sum_{m'} \rho TL^{m'} \cdot \rho EC^{m'} \cdot \rho TF^{m'} \quad (6)$$

Where:

$E_{[mc]}$ = Energy consumption for the mode change scenario;

m' = adjusted mode change to the mode share.

Also, fuel consumption is constrained by simulating a reduction in the trip frequency ($\rho RFm'$) of residents to the activity location. Reducing trip frequency will reduce transport energy consumption. This constraint will affect all residents equally until the limit of this variable is reached. This scenario is calculated using Equation 7. The adjusted trip frequency (ρRFm) is reduced until the energy consumption of the scenario ($E_{[fc]}$) is equal to the applied constraint ($E_{[ct]}$).

$$E_{[fc]} = \sum_m \rho TL^m \cdot \rho EC^m \cdot \rho RF^m \quad (7)$$

Where:

$E_{[fc]}$ = Energy consumption for the frequency change scenario.

Finally, mode share and trip frequency are adjusted to their limits to determine the resilience of the built environment. The minimum energy consumption ($E_{[me]}$) is represented mathematically as in Equations 8 and 9. The mode share (m') is adjusted to force residents located at a distance less than d_{max} to use a non-motorised mode.

$$E_{[me]} = g_{[me]} \cdot E_{[cu]} \quad (8)$$

$$E_{[me]} = \sum_m \rho TL^{m'} \cdot \rho EC^{m'} \cdot TF^{m'}_{\min} \quad (9)$$

Where:

$g_{[me]}$ = the maximum possible percentage constraint that can be applied to the current situation ($E_{[cu]}$).

Step Five: Modify The Built Environment

Modification of the built environment involves alterations to the transport technology and the suburban layout. Firstly, modifications are made to the transport technology in terms of changing the mode type characteristics of the study region (e.g. implementing a policy that requires more fuel efficient vehicles). Equation 10 expresses the resultant energy:

$$E_{[tc]} = \sum_m \rho TL^m \cdot \rho ME^m \cdot \rho TF^m \quad (10)$$

Where:

$E_{[tc]}$ = Energy consumption for modified transport technology scenario; and

ρME^m = Modified energy consumption distribution of new transport technology.

The behaviour change limits are applied to determine the new resilience of the modified built environment. Using Equation 11, energy consumption is computed and re-calculated if the modified built environment is still not 100% resilient.

$$E_{[me]} = \sum_m \rho TL^{m'} \cdot \rho ME^{m'} \cdot \rho RF^{m'} \quad (11)$$

Also, as a long-term solution, spatial re-design of the study region can contribute to reducing energy supply in order to allow the activity of interest to be reached without the use of transport fuel. This emulates relocation and addition of new activity locations in the study region. They are placed so that all residents are located at a distance less than the limit d_{max} previously determined in step three. The new energy consumption is represented as:

$$E_{[ac]} = \sum_m \rho ML^m \cdot \rho EC^m \cdot \rho TF^m \quad (12)$$

Where:

$E_{[ac]}$ = Energy consumption for new activity location; and

ρML^m = Modified trip length distribution as a result of activity locations.

Given the minimum number of activity locations to achieve, the modified trip length distribution is calculated after the addition of activity locations that ensure the maximum trip length is less than d_{max} . Maximum behaviour changes are applied to ensure that 100% resilience is achieved using equation 13.

$$E_{[me]} = \sum_m \rho ML^{m'} \cdot \rho EC^{m'} \cdot \rho RF^{m'} \quad (13)$$

Step Six: Analyse The Effectiveness Of Behavioural And Physical Changes

The effects of the behavioural and physical changes simulated for the suburb are assessed by verifying the effectiveness of behavioural changes against those related to physical changes. Each change made to the suburb is then assessed to determine how realistically it could be implemented or accepted by the residents of the suburb.

CASE STUDY

Almost all New Zealand vehicles operate with fossil fuels diesel or petroleum (8). These oil products are largely sourced from world markets, and oil produced in New Zealand offers very little buffer to reliance on the world oil market (9). This makes New Zealand, along with many other countries, strongly affected by fluctuations in the world oil market. For transport, no alternative fuel is readily available (10) (11).

As observed in other major New Zealand urban centres, Christchurch has experienced significant low-density growth associated with high levels of individual motorization. Christchurch is the largest city in the South Island with a population of 338,800 people living in the city and an additional 78,000 people living in the surrounding regions (12). The land area comprises of 45,240 hectares. Car travel is the most common mode of travel in Christchurch (1.14 vehicles per person, 2003). In the Canterbury region of New Zealand, private vehicle transport accounts for the majority of transport fuel consumption (13).

One of the most recent suburban developments on the fringe of Christchurch City is Northwood. The layout of the Northwood subdivision can be seen in Figure 1a. The plan shows only one food retail outlet servicing the entire Northwood development. This food store is located at the entrance to Northwood. The development comprises of houses and a network of roads allowing all residents to access their activities through use of (in most cases) private vehicles.

In the next sub-sections, the method presented in the second section is applied to assess the reliance on transport energy for accessing a food shopping activity within the Northwood suburb.

Defining The System For Study (Step One)

According to recent research conducted by Buchanan (14), each Northwood household travels on a weekly basis to the food retail outlet (using the road network) to purchase their food. The current mode share of Northwood residents travelling to food stores is 94.6% vehicle and 5.4% non-vehicle (only 5.4% of residents live within 300 metres of the food store).

Defining Physical And Behavioural Variables And Estimate The Current Energy Consumption (Step Two)

The initial energy consumption calculation for Northwood is estimated in litres of petroleum consumed per week. Mode choices are limited to: motorised vehicle modes ($m=1$); and all other modes ($m=2$). As for estimating the trip length distribution, a GIS transport package was employed to estimate the on-network travelled distance from each household in Northwood to the food store. Figure 1b represents the transport network in a georeferenced data set according to New Zealand Map Grid, 2000. 695 residences were grouped into increasing 40 metre 'bands' of households. Each group of residences has then been given an average distance from the food store, e.g. houses in the 0 to 40-metre 'band' from the food store have all been reallocated to an average distance of 20 metres. Figure 2a represents graphically the resulting trip length distribution.

Households using non-motorised modes are assumed to be the closest households to the food store. It can be observed that households in the group 260 metres and less (accumulated

percentage of 5.4%) from the food store will use a non-motorised vehicle mode. All other households will be assumed to be using a motorised mode.

Applying equations 1 and 2 and considering motor vehicle registration data (8), energy conversion rates (9) and the New Zealand vehicle energy consumption reference guide book (15), energy consumption was computed. When converted to an energy probability distribution ρEC , the fitted data is best approximated by a log-logistic function as shown in Figure 2b.

The trip frequency distribution ρTF for Northwood has been estimated to best fit a Weibull distribution as shown in Figure 3a. Applying Equation 4 for the motorized transport mode ($m=1$), the current energy consumption was estimated as shown in Figure 3b.

Performing The Risk Analysis (Step Three)

This risk analysis determines the ability of the 'built environment' to provide accessibility to food stores in the Northwood suburb during a transport fuel reduction or shortage. A transport energy constraint could be brought about in a number of ways; through the reducing world oil reserves, environmental policy or a war affecting the supply chain. On the other hand, reliance on transport fuel is a function of Northwood's residents' behaviour, the built environment and personal attributes of Northwood residents.

As for the behaviour, the flexibility of Northwood's residents' attitude affects the risk faced by the residents. The ability to move to a non-motorised vehicle mode or reduce the frequency of vehicle trips to the food store will reduce reliance on transport fuel. There are limits to the extent that behaviour can be modified. For example, the trip frequency cannot be reduced below the shelf-life of consumables such as milk and bread.

In terms of the built environment, the physical location of residents' households from the food store and the type of vehicle they drive will be a determinant of reliance on transport fuel. The Northwood layout places some households at over 1.5km (along the road network) from the food store. Feasible continuous shopping trips to the food store using non-vehicle modes have been decided as 750 metres (a 1.5km return trip). This is more than double the current observed trip distance (less than 300 metres) for non-motorised vehicle trips. Setting the maximum feasible non-motorised mode distance to 750 metres excludes approximately half of Northwood residents from using non-motorised modes.

Additionally, mobility and physical health of residents will also play a part in determining their reliance on transport fuel. 100% of residents over 60 years old, in the Northwood development, use a car to access the food store regardless of their location from the store. Residents with mobility or health concerns will be at an even greater risk if they are not living close to a food store.

Combining these risks, the impacts of a fuel reduction or shortage to residents with a high reliance on transport energy fall into two groups; change in the accessibility to the food store and loss of access to the food store. Change in accessibility would be as a result of behaviour modifications, e.g. a change in mode or frequency of trips to the food store. On the other hand, loss of access to the food store would be caused by physical incapability and would result in starvation or actions to regain access to the food store, including relocating closer to the food store. Table 2 displays the likelihood of the identified impacts occurring for two groups of residents; fit/healthy and elderly/mobility impaired. These groups are further divided into three subgroups classed by their distance from the food store. The group with less than 300 metres from the food store represents current behaviour. The group greater than 750 metres represents

those living further than the defined maximum distance of 750 metres. The group between 300 and 750 metres is the transitional group of residents.

Estimating Energy Constraints And Behaviour Change (Step Four)

Changes were simulated for mode share and trip frequency and then the resilience of Northwood's built environment was determined using the behaviour change limits defined in the previous section.

In a modal shift scenario and trip frequency left unchanged. It includes 10% transport energy reductions until the limit for using non-motorised modes is reached (750 metres). The residents closest to the food store are required to shift from a motorised vehicle to a non-motorised mode until consumption equals the applied energy constraint. With reference to the schematic representation in Figure 4, the effects of each simulation are clearly visualised. The expanding circles show how far residents will be required to travel using non-motorised modes for each 10% energy reduction. The outer circle is the maximum feasible trip distance for non-motorised vehicle modes (750 metres).

Despite its informative nature, Figure 4 only roughly represents the situation. The true representation of residents using non-vehicle modes is not exactly expanding 'circles' because the actual distances are calculated along the road networks and pedestrians may take 'shortcuts'. Figure 4 is only intended to be used as a visual aid of the situation.

In a scenario involving changes to trip frequency (number of trips a household makes to the food store per week) and mode share held constant at the current level (5.4% using non-motorised modes), the application of energy constraints (one trip per week for all residents) generated the results shown in Figure 5. The maximum possible constraint is not illustrated as this requires all households to perform 1 trip per week and therefore is not a distribution. Trip frequency (90% probability limits) decreased from between 1.2 and 2.7 trips per week to between 1.1 and 1.6 trips per week when a 30% constraint was applied.

Finally, the maximum feasible energy constraint for Northwood was determined by applying the maximum behaviour change limits. In the model, all residents living less than 750 metres from the food store are using a non-motorised mode and all other households make only 1 trip per week to the food store. The energy distribution for the simulation is shown in Figure 6a and represents a 63.9% transport energy reduction from the current situation.

The minimum feasible energy consumption represents the functional limit of the Northwood region. The possibility for behaviour change provides the resilience that the built environment of Northwood offers. The built environment is not 100% resilient because transport energy is still required to access the food store. In line with the method, options for modifying the built environment were simulated until 100% resilience was attained.

Modifying The Built Environment (Step Five)

Two aspects of Northwood's built environment were investigated: transport technology; and the location and addition of food stores. Transport technology was modified by importation of higher fuel-efficient vehicles to the Northwood region. The most fuel-efficient mode (e.g. motorcycle) on the market consume approximately 2.5 litres/100km. A distribution of vehicles with a mean consumption of 5 litres/100km represents a doubling of fuel efficiency from the current situation. This vehicle energy consumption distribution is shown in Figure 6b. The 90%

probability limits for this distribution placed vehicles between consumption limits of 2.45 and 8.18 litres/100km.

Energy consumption is reduced by 53.1% when new vehicles were introduced to the Northwood region. This reduction required no behaviour change from the residents. As residents modify their behaviour to reduce consumption, greater energy reductions are achieved with the new transport technology.

Applying the maximum possible behaviour changes for the new transport technology produced a maximum possible transport energy reduction of 83.1%. The minimum energy consumption distribution for the modified built environment is displayed in Figure 7. Modifying the built environment with the introduction of new technology (fuel efficient vehicles) increased the resilience of the built environment from 63.9% to 83.1%. To achieve 100% resilience, relocation and addition of food stores was simulated.

Firstly, relocating or adding new food stores provides feasible access to all residents without using a motorised vehicle mode. Food stores were located at a distance of less than 750 metres from all Northwood residents. Two options were investigated: Option A) three additional food stores (Figure 8a) and keeping the current food store fixed produced the results shown in and Figure 8b; and Option B) Relocation of the current food store and addition of new food stores if required (Figure 8c) produced the energy distribution as presented in Figure 8d. Both options provided a 100% resilient built environment and both options required the addition of three new food stores. However Option B required one less food store than Option A.

Analyzing The Effectiveness Of Behavioural And Physical Changes (Step Six)

It can be observed that substantial reductions in transport energy were achieved by changing the behaviours of Northwood residents, but changes in the built environment produced the greatest reduction in transport energy. Individually changing modal share and frequency reduced consumption by 31.9% and 46.9% respectively. Frequency change produced the greatest reduction in transport energy, mostly affecting those residences furthest from the food store that use the greatest amount of transport fuel.

Transport energy was reduced by 63.9% when behaviour changes of trip frequency reduction and an increase in non motorised modes were applied. This is a significant reduction and provides considerable flexibility for this suburb design. Flexibility provides for time to change behaviour or the physical layout of the suburb when oil constraints are realised. The only concern facing the suburb would be a complete supply shortage; this would severely affect the residents still reliant upon transport energy.

On the other hand, the importation of fuel efficient vehicles had a considerable affect, resulting in a 53.1% estimated energy reduction without changing behaviour. Similar results would be achieved for any suburb, as vehicle type is independent of the spatial pattern of the suburb. Another result transferable to other suburbs is vehicle change combined with trip frequency reduction; for Northwood this was estimated as a 75.1% energy reduction. The introduction of new vehicles fails to reduce the reliance on motorised vehicles to zero. To completely reduce reliance on transport fuel, reliance on motorised vehicles must be eliminated, which can only be achieved through modification of the spatial layout.

In achieving zero reliance on motorised vehicles through addition of new food stores, a 60.5% energy reduction was estimated. This reduction in energy would occur without any mode share or trip frequency changes. Energy reduction is achieved because of the large increase in

number of residents located within 300 metres of a food store. This allows a much greater number of residents to use non-motorised modes to access the food store (approximately a 27% increase). In addition, residents still using a motorised vehicle have lesser distances to travel to the closest food store. 100% resilience is achieved through the addition of three new food stores (a total of four stores). However if the suburb had initially been planned to provide food stores within 750 metres of all residences, a total of only three food stores would have been required.

CONCLUSIONS

The uncertainty of future energy scenarios and the current tendencies of energy usage in transportation have instigated this study. Recent fuel shortage events and soaring petroleum prices combined with urban sprawl development tendencies and serious concerns about fossil fuel reserves indicate that energy has to be carefully incorporated in the transportation planning process. Although many planning authorities and scholars have dedicated considerable efforts in relating energy consumption with urban development forms, energy constraints such as fuel shortage events or crisis have been practically ignored. Moreover, the long-term consequences of planning decisions have not totally contemplated extremely high energy requirements that society may face in the future versus the likelihood of oil total or partial depletion scenarios.

In order to incorporate energy as a constraint in transportation analysis and building up from our previous research work (16) (17), we presented a method to assess current and future reliance on transport energy based upon the application of risk analysis techniques. Despite the simplicity of its assumptions in terms of travel behaviour changes after the fuel shortage event or crisis, the method attempts to provide a preliminary assessment that determines the vulnerability of suburban communities.

Case study results have shown that considerable energy reductions would be required if energy shortage scenarios occurred. Moreover, they demonstrate that considerable changes in terms of travel behavior and in the activity system could generate sustainable developments in the future. Clearly, these findings are in accordance with previous studies on sustainability issues, nevertheless this research's novelty lies creating information about community exposed risks and how changes may contribute to alter the vulnerability to future events.

This research is expected to provide an opening for further research that may eventually lead to the development of future tools. A natural progression from this work is obtaining accurate data on how residents of suburban developments would behave during and after fuel shortage events or crisis. Further efforts to empirically obtaining information on travel behaviour and activity location changes should be conducted. On the other hand, a long-term goal should be the development of transport energy modelling tools that could assist in the planning stage of suburban developments where energy is considered an important factor. The most significant aspect of this area of research is that energy requirements for future suburban scenarios could be assessed before they are carried out.

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TABLE 1 Example of risk impact probability table

		Risk (Reliance on Transport Energy)					
		Fit/Healthy			Elderly/Mobility Impaired		
		$<d_a$	$d_a - d_{max}$	$>d_{max}$	$<d_a$	$d_a - d_{max}$	$>d_{max}$
Impacts	Distance to the activity location	Low	Low	Medium	Medium	Medium	High
	Loss of access to the activity	Low	Medium	High	Medium	High	High
	Modified access: Behaviour change	Low	Medium	High	Medium	High	High

Impacts	Risk (Reliance on Transport Energy)					
	Fit/Healthy			Elderly/Mobility Impaired		
	Distance from Food Store (metres)	<300	300 -750	>750	<300	300 -750
Distance from Food Store (metres)	<300	300 -750	>750	<300	300 -750	>750
Loss of Access to Food Store	Low	Low	Medium	Medium	Medium	High
Modified Access: Behaviour Change	Low	Medium	High	Medium	High	High

Probability of Impact Occurring: High, Medium, Low

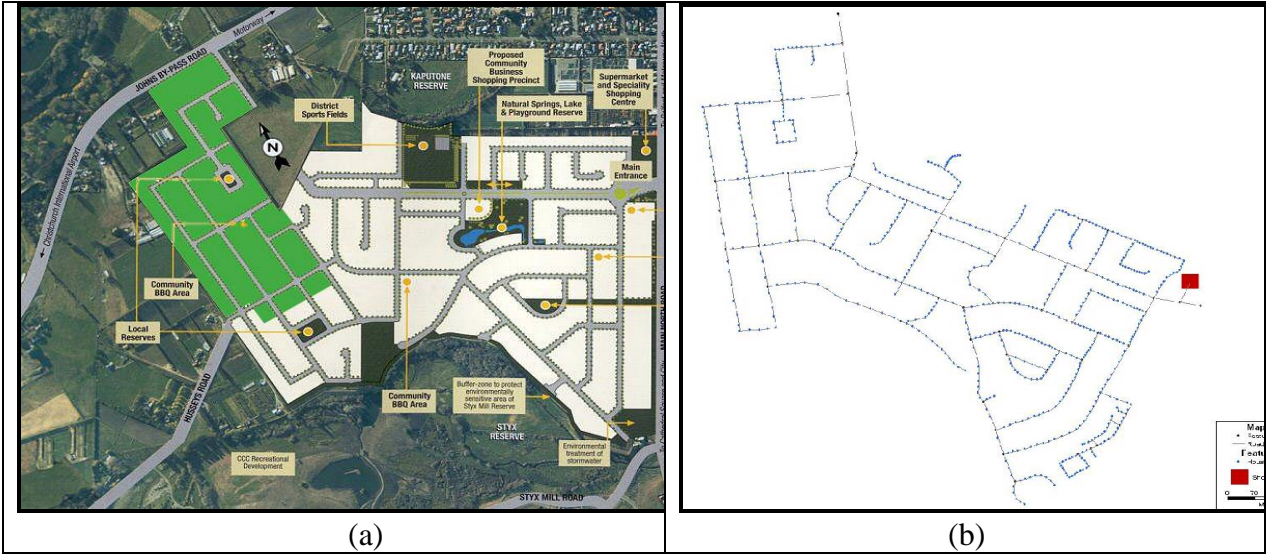


FIGURE 1 (a) Northwood development layout (b) Northwood network map

Source: www.northwood.co.nz (not to scale)

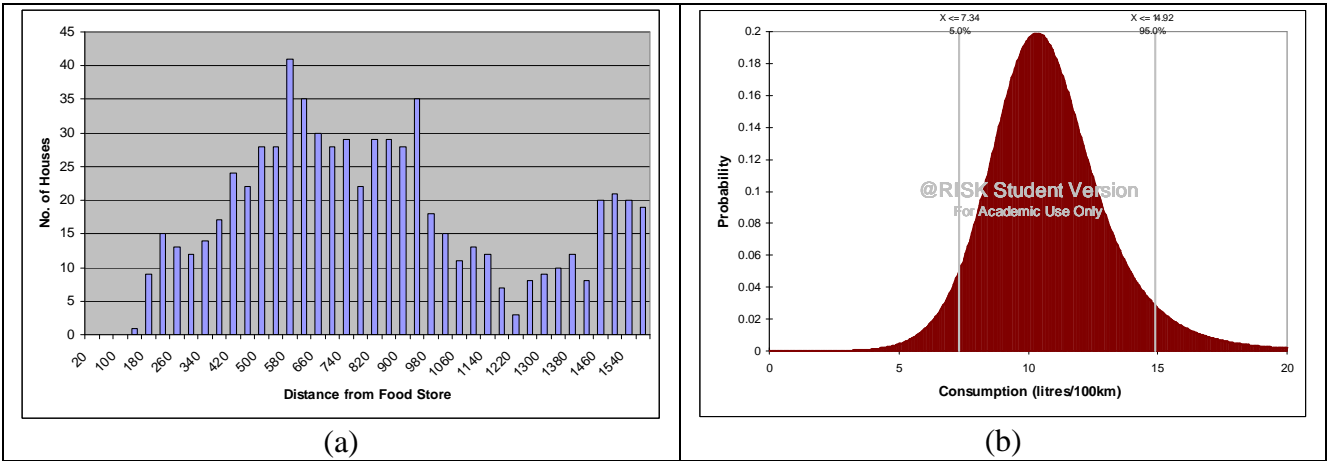


FIGURE 2 (a) Trip length distribution; (b) energy consumption distribution of vehicles

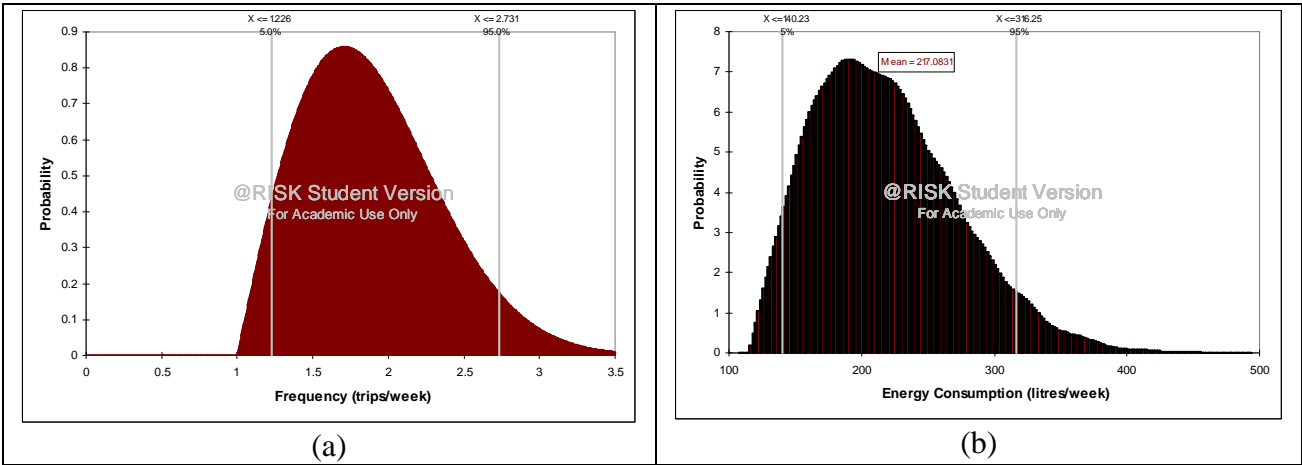


FIGURE 3(a) trip frequency distribution; (b) Energy consumption distribution

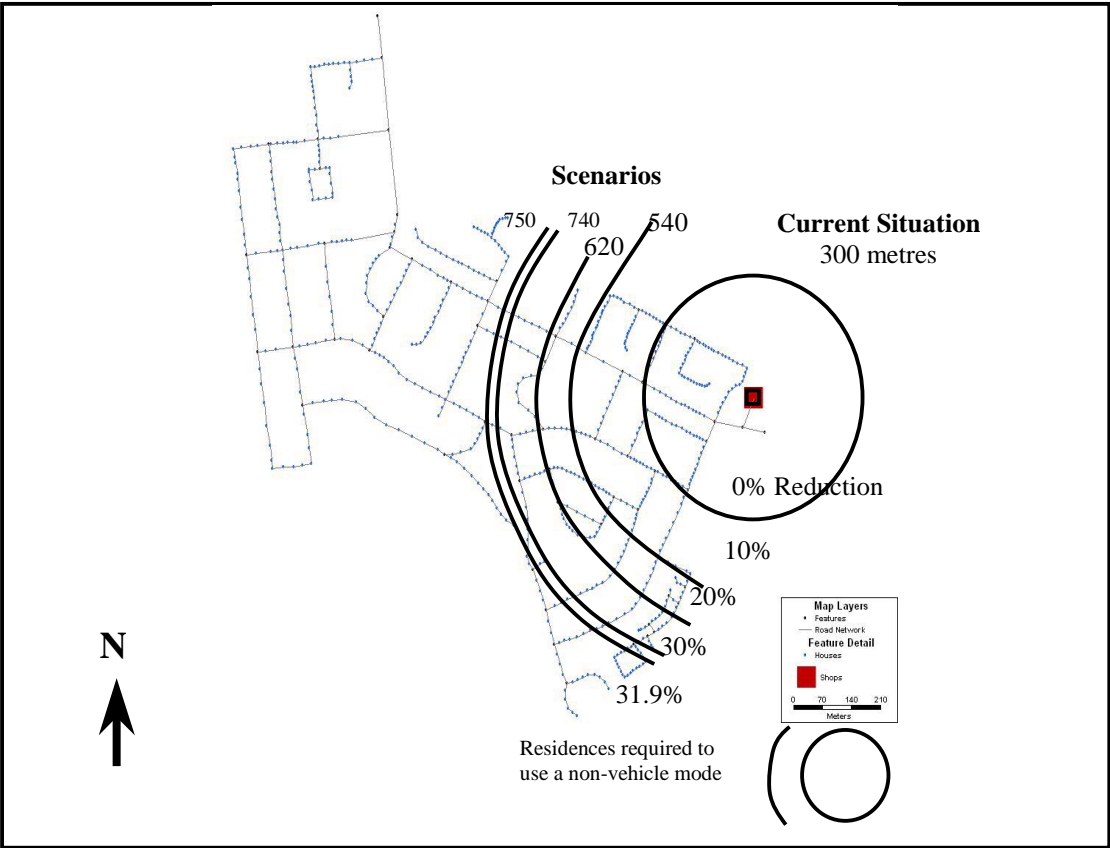


FIGURE 4 Iso-lines showing how constraining transport energy increases non-motorised modes

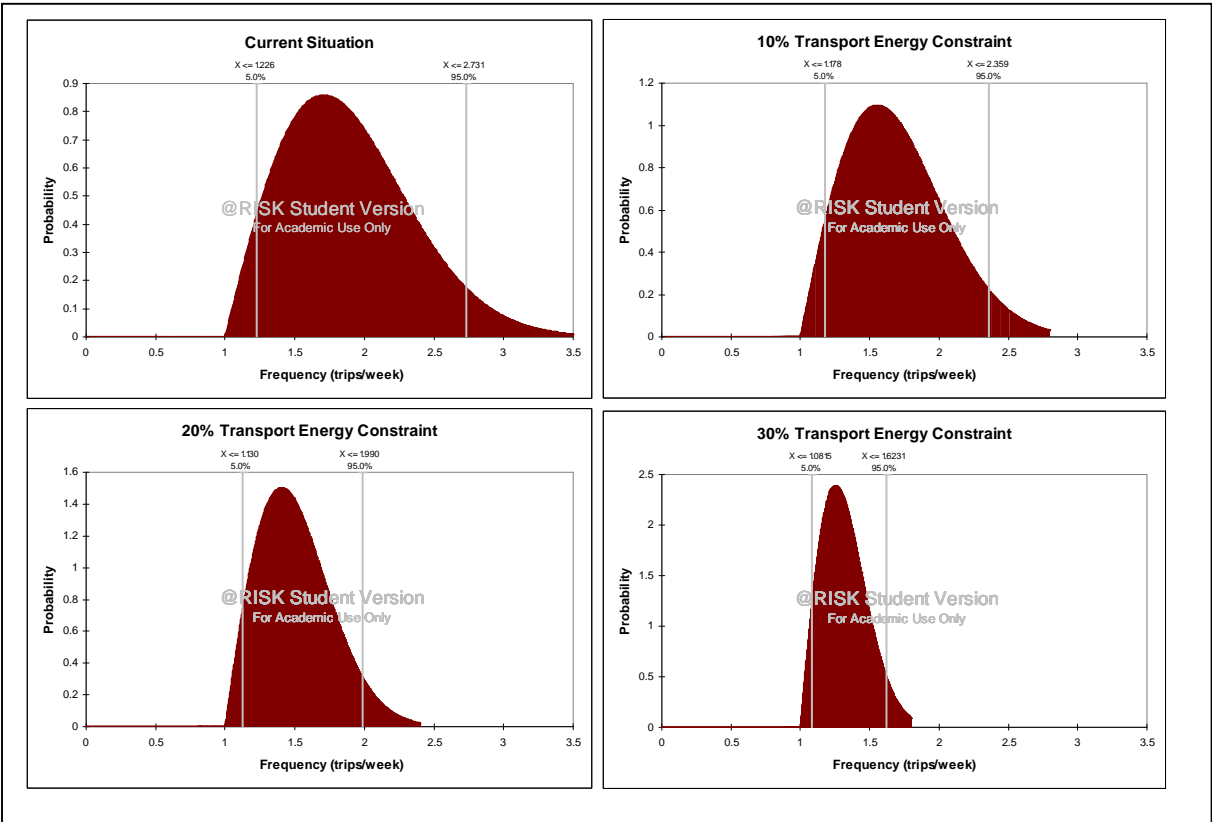


FIGURE 5 Effect of constraining transport energy on trip frequency distribution: (a) Current Situation; (b) 10% Constrained Transport; (c) 20% Constrained Transport; (d) 30% Constrained Transport

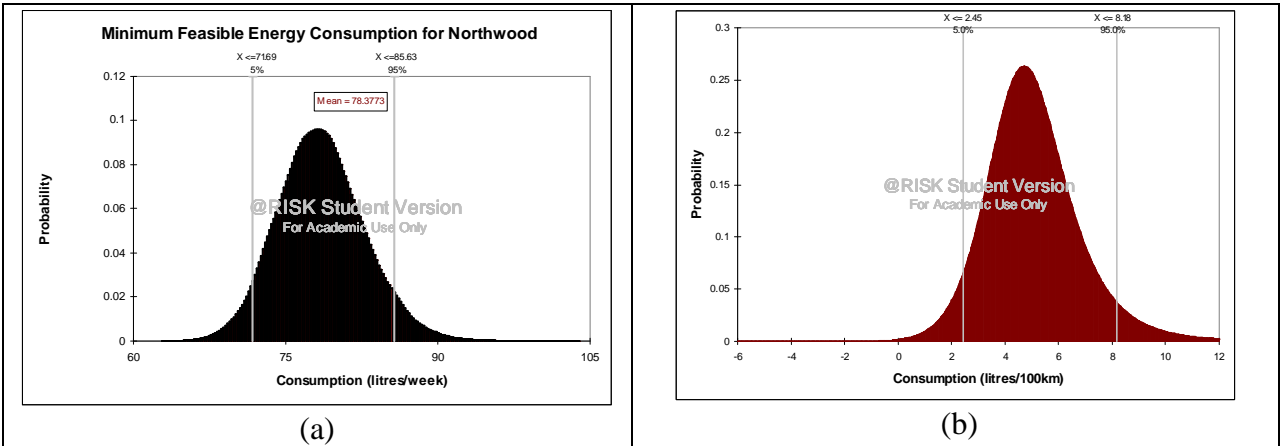


FIGURE 6 Energy consumption probability distribution: (a) Using behaviour change limits; (b) new vehicles

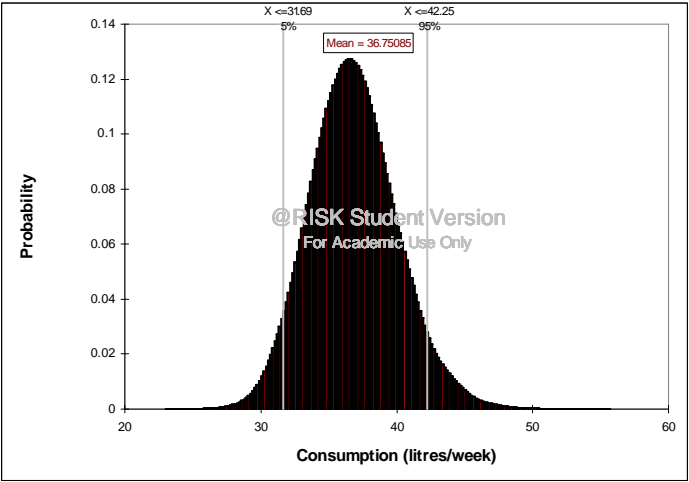


FIGURE 7 Minimum feasible energy consumption distribution with introduction of new vehicles

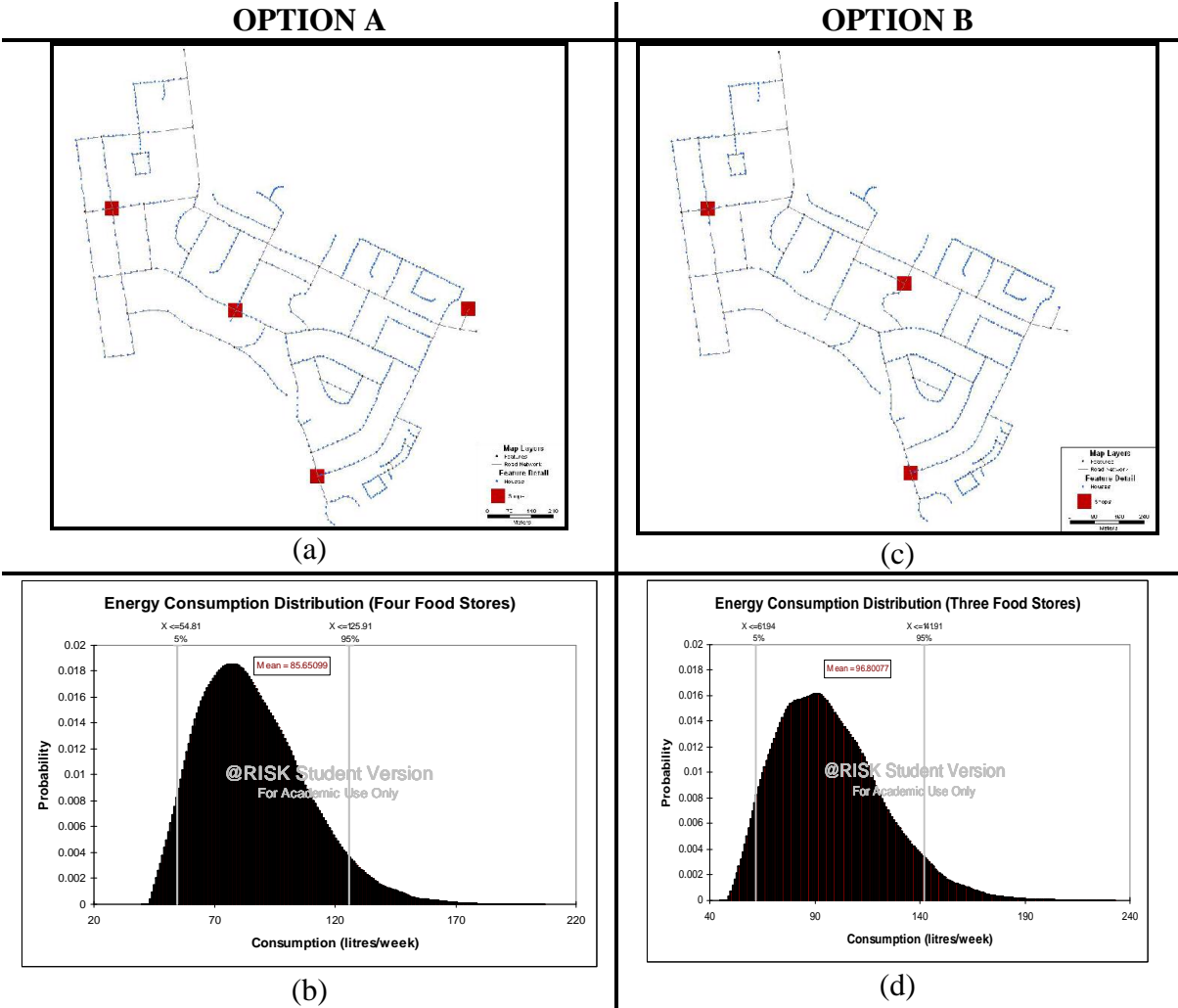


FIGURE 8: (a) Option A layout; (b) Option A energy consumption new food stores; (c) Option B layout; (d) Option B energy consumption